Dog bite Emergency department presentations in Brisbane metro south: Epidemiology and exploratory medical geography for targeted interventions

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ABSTRACT

Dog bites are a recognized public health issue due to their impact on human and animal health/welfare. This study aimed to investigate demographic and geographic disparities in the epidemiology of dog bites presentations reported to the emergency departments of the four main public hospitals in the Metro South region of Brisbane, Queensland, Australia.

Dog bite patient hospitalization data geolocated to the street address were collected from clinical records management systems from the four main public hospitals in the Metro South Hospital Health Service region of Queensland for a 5-year period (ie. 01/07/2013 to 30/06/2017). We investigated the epidemiology of three clinical outcomes including probability of paediatric cases (paediatric vs. adult), probability of dog bites to the head (head injury vs. other injury), and probability of re-presentation to the ED following their initial dog bite (yes or no) by way of univariable then multivariable Bernoulli logistic regression models including patient postcode as a random effect. Residual semivariograms were created to identify spatial trends in the medical geography of dog bites and binomial geostatistical models were created to predict the probability of the outcomes of interest in Brisbane Metro south and surrounding suburbs.

Our results demonstrate that compared to adult dog bite cases, paediatric dog bite cases were significantly associated with bites to the head or face or neck (OR 14.65, $P < 0.001$), bites to the lower body (OR 4.95, $P = 0.035$) and larger dogs (OR 0.25, $P = 0.030$ for small dogs). The probability of head injuries was greater in younger age groups (17–39 OR 0.25, $P = 0.001$; 40–64 OR 0.15, $P = 0.001$; 65-above OR 0.14, $P = 0.029$). Attacks by small dogs were more likely to inflict head wounds than large dogs (OR 6.12, $P < 0.001$). The probability of re-presentation was lower in patients bitten by medium sized dogs (OR 0.29, $P = 0.027$) than larger dogs. Our predictive maps showed significant clustering of paediatric case probability in the Logan city and Redlands councils associated with socioeconomic status of the places of residence.

In conclusion, our findings demonstrate significant demographic and geographic heterogeneity in dog bite ED presentations. Public health interventions to reduce the burden of dog bites should be targeted to the populations most at-risk in the areas identified in this study.

1. Introduction

Dog bites are a globally recognized public health issue in both developed and developing nations in that resulting injuries are significant sources of morbidity and mortality worldwide [1]. The impacts of dog bites can be measured in terms of their health impacts to individuals affected, economic costs of treatment and health service resources and animal welfare repercussions [2]. The global burden of animal bites is disproportionately felt in Africa and Asia where an estimated 55,000 people die annually as a result of dog-mediated injuries and disease [3]. This range of consequences justifies continued assessment of the epidemiology surrounding dog bite incidents, as well as local

contributing factors to develop improvements to existing public health policies regarding dog bite management.

There are a multitude of factors which contribute to the high morbidity and mortality associated with animal bites [4]. Dog bite events occur due to the interplay of a range of factors including: breed, age of the dog, age of the victim, the behavioural history of the dog and the victim, the extent of socialisation of the dog, the physical and mental health of the dog and the victim, and the behaviour of the dog and the victim preceding a bite incident [5–7]. An improved understanding of the role of these risk factors is fundamental to the development of interventions to reduce the impacts of dog bites but also to reduce the transmission of diseases associated with them [8].

There is evidence to suggest the seasonal effects on dog bite incidence by eliciting changes in human behaviour; although this is reported from countries with dramatic seasonal changes [9,10], and thus may not be relevant in countries with less seasonal variation. Some research has argued that dog breed is a significant risk factor for severe bites [11,12]; whilst contrasting research presents data suggesting that labelling specific breeds as inherently dangerous is ineffective in developing appropriate responses to increasing dog bite incidence rates [9,13–15]. Additionally, published research has suggested a relationship between the popularity of specific breeds with income levels [10], although the extent to which dog breed is a significant risk factor is unclear [16–18].

Increasing awareness with regards to the epidemiology of animal bite injuries amongst both healthcare providers and the general community is critical to reducing their overall health burden [4,19]. Globally the health burden of dog bites translates into tens of millions of injuries annually, with children being the population subgroup most at risk [1]. In addition to the transmission of zoonotic diseases such as rabies, dog bites inflict disfiguring injuries often requiring reconstructive surgery, cause disfigurement, disability, infection, death [3,20,21], and can have lasting psychological effects [10,12,22–24]. Effective characterization of risk across the three key areas of dog bite burden including paediatric cases, head injuries and re-presentations provides greater opportunities for the development and implementation of targeted interventions to reduce dog bite burden [25].

In Australia an estimated 100,000 dog bites are reported annually, with an average of 2061 requiring hospitalization for treatment each year [26]. Previous studies have estimated the annual cost associated with dog bite treatment in Australia at over AUD$7 million [5]. Paediatric bites are of particular interest as they are associated with a higher likelihood of requiring hospitalization [27], which corresponds with higher treatment costs associated with admissions, treatment, and long-term wound management [5]. In Australia, dog bites account for 60.7 per 10,000 ED presentations in paediatric populations, and 12.9 per 10,000 ED presentations in adult populations [28], and account for 80% of all bite wounds with ED presentation [29]. Given these trends and the limited availability of data characterising dog bite attacks in Australia [30], developing mechanisms to understand the role of different risk factors is essential to their long term management [31].

The primary aim of this study is to quantify the epidemiology of dog bite injuries in South-East Queensland, including determining the relevant factors for paediatric morbidity, dog bite head injuries and re-presentations and risk factors which determine the geographical distribution of dog bite outcomes.

2. Materials and methods

2.1. Ethical clearance

HREC Reference number: HREC/17/QPAH/851
Protocol title: Emergency Department presentations with dog bites: epidemiology, treatment efficacy and geographical spatial analysis (TEGS study).

2.2. Target population and study design

The target population of the study included all ED presentations for dog bites in the Metro South region of Brisbane from four public hospitals. The hospitals of interest were the Princess Alexandra Hospital (PAH), the Queen Elizabeth II Hospital (QEII), Logan hospital (LGN) and Redlands hospital (RED) (Fig. 1). The Metro South region of Brisbane and these four hospitals provide healthcare service to approximately 23% of Queensland's population and covers an area of roughly 3856 km^2. This study involved a retrospective cohort study for the period 01/07/2013 to 30/06/2017 inclusive (Fig. 2).

In total our initial database included 1925 patient records across the four hospitals, with 882 (45.8%) female patients and 1043 (54.2%) male patients. There were a total of 394 (20.5%) paediatric cases and 1531 (79.5%) adult patients. The initial dataset was refined by removing patients incorrectly selected in the initial data retrieval, removing duplicate presentations (repeat ED presentations within 7 days were considered the same event unless explicitly stated otherwise in the clinical notes), removing patients who either were not permanent residents of the Metro South region or were not bitten in the Metro South region, and removing patients with missing or incomplete information in their clinical notes. After refining the dataset the total patient numbers for this study were 1616, with 738 (45.7%) female patients and 878 (54.3%) male patients. These corresponded to a total of 349 (21.6%) paediatric patients and 1267 (78.4%) adult patients available for analysis. Data available for these patients included unit record number (URN), present visit number, hospital facility attended, arrival date, arrival time, departure date, departure time, age, gender, patient address, postcode, mode of arrival, reason for ED presentation, departure status, departure destination, presenting problem, location of incident, type of dog, size of dog, location of bite, length of stay, national emergency access target compliance, triage, Queensland weighted activity units, treatment time, catchment, and re-presentation. Following preliminary analysis, information on the reason for re-presentation and prior behaviour to an attack was extracted from the patient file and included (where available).

Socio-Economic indexes for areas (SEIFA) data were retrieved from the Australian Bureau of Statistics [32]. SEIFA data were provided for greater Brisbane suburbs as percentiles. Further to that, co-ordinates of dog parks were obtained from relevant city council websites and hospital co-ordinates were obtained from Google maps. Human population density from 2017 (with a resolution of 3 arc approximately 100 m at the equator) was obtained from the WorldPop project site. The nearest distances between suburb locations and dog parks and hospitals, and human population data extraction per suburb was performed using ArcMap version 10.7.1.

2.3. Statistical analysis

In our analyses three outcomes of interest were considered: probability of paediatric cases (paediatric vs. adult), probability of dog bites to the head (head injury vs. other injury), and probability of re-presentation to the ED following their initial dog bite (yes vs. no). We analysed our dataset in three progressive phases for each outcome of interest. First, to provide insights into the association between each outcome of interest and variables identified in each patients' clinical notes (Table 1) univariable analysis was performed using Bernoulli logistic regression models including patient postcode as a random effect to account for clustering of dog bite incidents per exposure location. Variables with a *P*-value of 0.20 or lower were considered significant and retained in the next stage of analysis. The second stage of analysis involved arriving at a final multivariable Bernoulli logistic regression model for each outcome of interest using a backward stepwise regression procedure. This process allowed for the identification of variables which were confounders, by assessing the impact of their removal on the co-efficients of the remaining variables. If the removal of a variable resulted
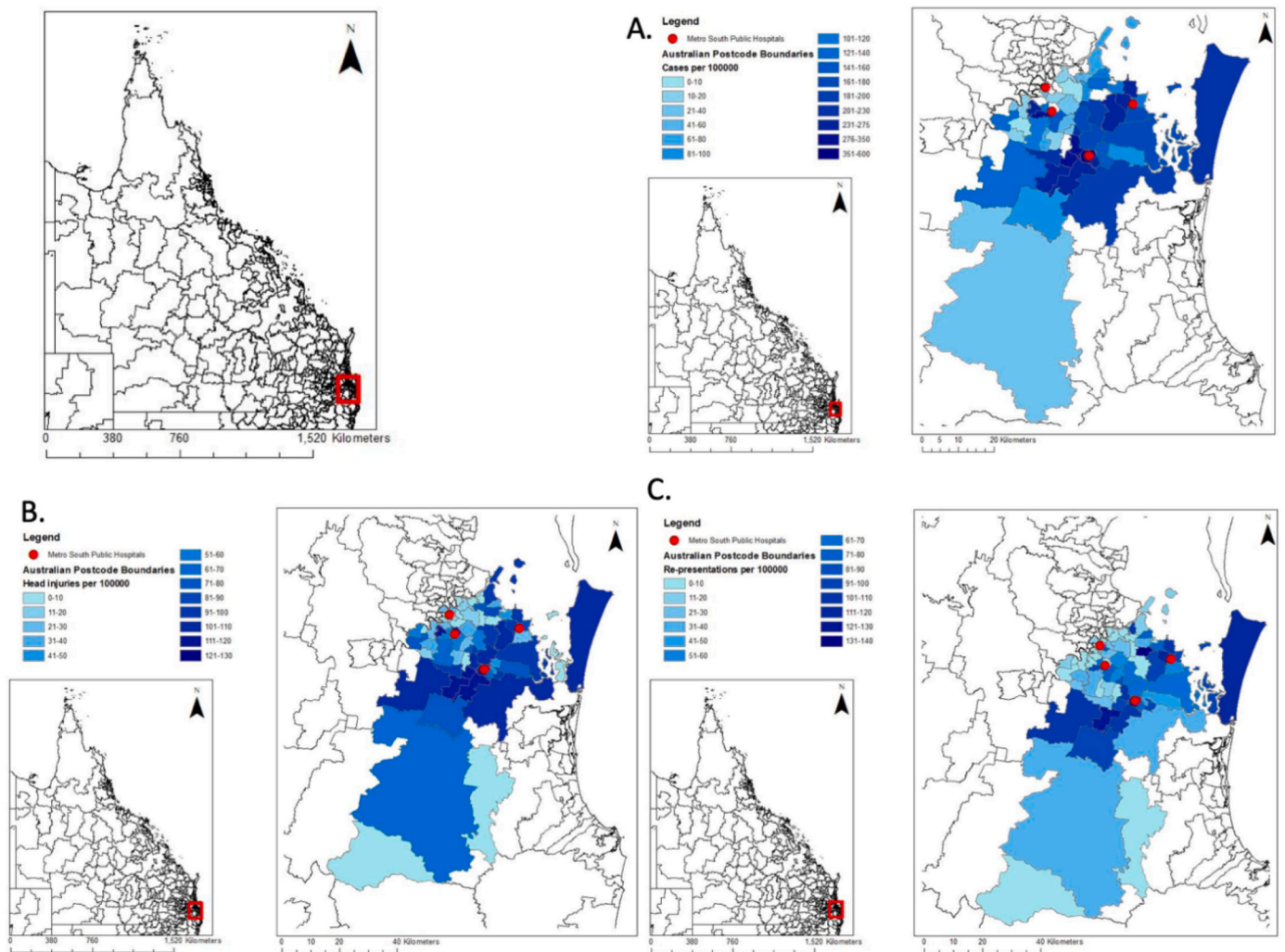
Fig. 1. Geographic distribution of dog bite injuries 2013–2017 in Brisbane Metro North Health Service. A. Paediatric incidence B. Head injury incidence and C. *Re*-presentation incidence.

in a ± 25.0% change in the coefficient of any of the remaining variables then it was considered to be a confounder, and retained in the multi-variable model. Risk factors that were significant at a *P*-value of 0.05 or lower were retained in the final multivariable regression model. Two multivariable models were developed to determine the risk factors associated with the probability of re-presentation. The first included the variables: age, sex, and bite location. The second included the variables: age, sex, dog size, and bite location. Due to a lower AIC the second model was considered the best model for this outcome. Multivariable model fit was evaluated based on the Akaike information criterion (AIC); the lower the AIC value the better the fit of the model relative to models of the same outcome with higher AIC values, but we also considered the number of observations in the model as relevant. Univariable and multivariable Bernoulli logistic regression analyses were performed using Stata version 13.1 (Stata Corporation, College Station, TX, USA).

2.4. Analysis of residual spatial dependence

Model residuals from multivariable models for each outcome of interest were extracted for each observation in the dataset and linked to the corresponding street address of the patient in order to test for the presence of residual spatial autocorrelation using a semivariogram. Residual semivariograms are a graphical re-presentation of variability of a variable as a function of separating distance between pairs of co-ordinates where the variable is measured [33]. The most important parameters in describing semivariograms are the nugget, partial sill, and range [33,34]. The nugget is a value representing random spatial variation, which may arise due to measurement errors, very small scale spatial variability, or random variation inherent in the data [33,34]. The partial sill is a re-presentation of the spatially auto-correlated variation, which may be the result of spatial heterogeneity in important drivers of bite events not measure in the current multivariable models [33]. The range is the distance at which spatial autocorrelation no longer occurs and indicates the size of disease clusters in the models [33]. Ultimately, a semivariogram identifies whether there is geographical clustering and quantifies the extent of variability in the models unaccounted for by the variables used in the multivariable models. If all the variables in the multivariable model explained the geographical clustering, then there would be no residual spatial variation and the semivariogram curve would be flat. In addition semivarigrams provide an estimated average size in kilometres of dog bite clusters which is of operational importance if stagies to minimise dog bites are to be deployed in the affected communities. If residual spatial variation is not accounted for by the variables included in the multivariable model for each outcome, sub-sequent investigation is needed such as geostatistical modelling [33,34].

2.5. Predictive risk mapping and model validation

Binomial model-based geostatistical models of each of the three outcomes (ie. paediatric dog bite, head injury from dog bites, and dog
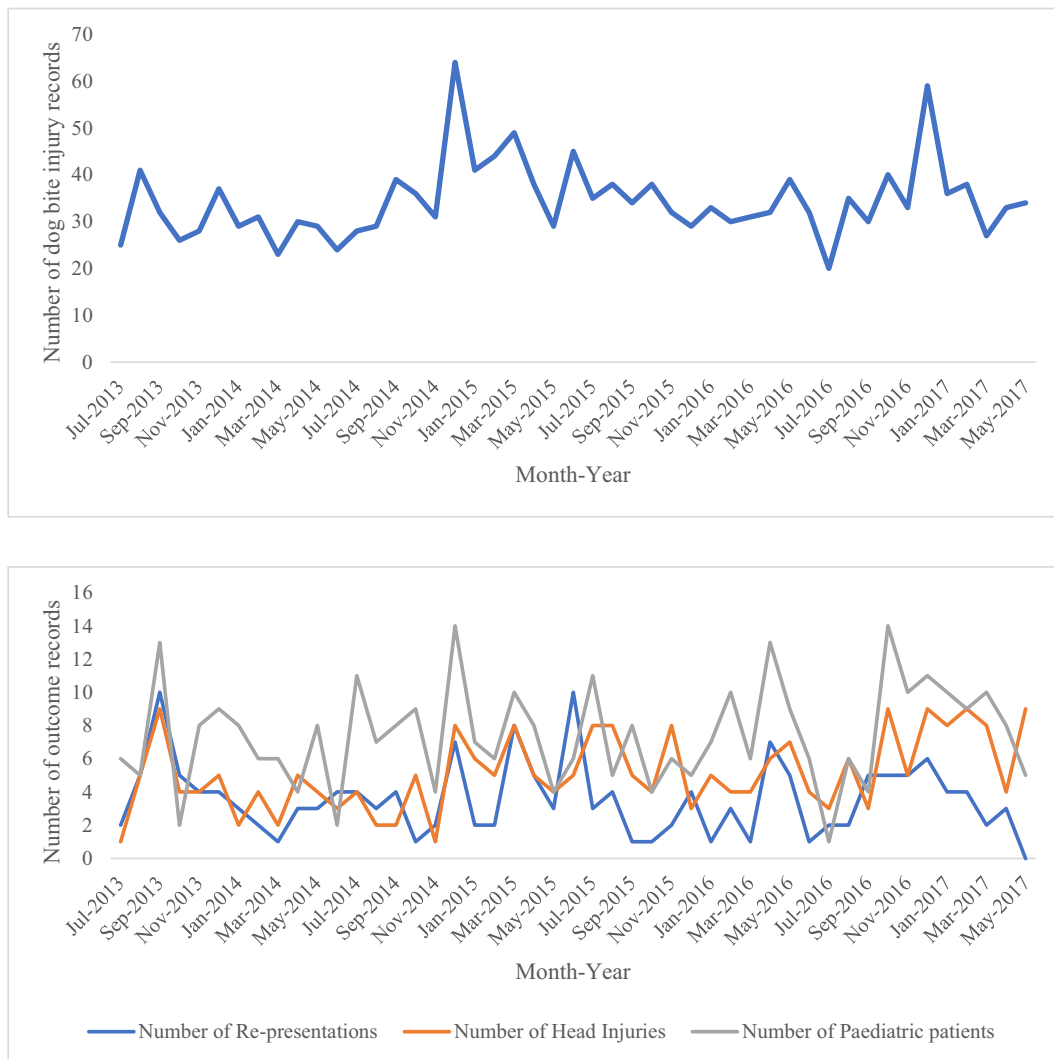
Fig. 2. The temporal distribution of dog bite injuries 2013–2017 in Brisbane Metro North Health Service. A. Total dog bite injury records B. Total records per outcome.

Table 1
Variables included in univariable logistic regression analysis.

Variables		Details
Individual Factors		
1	Facility	LGN, QEII, RED, PAH
2	Age	0–16, 17–39, 40–64, 65-above
3	Sex	Male, female
4	Location of incident	Outdoors, workplace or other residence (family or friend or neighbour), own residence
5	Dog type	Known to victim, unknown to victim
6	Dog size	Small, medium, large
7	Bite location	Head or face or neck, upper body, lower body, multiple
8	Prior behaviour	Playing with dog, separating fighting dog, other
9	*Re*-presentation	Yes vs. no
10	Head injury	Yes vs. no
11	Patient age group	Adult vs. paediatric

bites re-presentation) were built using the software OpenBUGS version 3.2.3 rev 1012. A total of 1600 individual observations at 155 suburb locations were included in the analysis. Individual-level covariates for the paediatric model included sex, and for the "head injury" and "re-presentation" models included two age categories (0–16 years and ≥ 17 years). For the purpose of this model, head injury is an inclusive term for

bites to the head or face or neck. Additionally, where a patient was bitten on the head or face or neck as well as on either the upper or lower body, this was allocated into the head injury category. Location-specific ecological explanatory variables included the Socio-Economic indexes for areas (SEIFA), distance to dog parks, distance to the four hospitals included in this study, and human population density. All ecological variables were extracted at the suburb of the patient's address and were standardised by subtracting the mean and dividing by the standard deviation. Each model included a geostatistical spatial random effect to account for residual spatial autocorrelation; models were run for an initial burn-in of 2000 iterations, followed by an additional 5000 iterations from which parameter results were stored. The outputs of the Bayesian models are distributions termed 'posterior distributions', which represent the uncertainty associated with the parameter estimates. Posterior prevalence predictions and standard deviations of the prevalence prediction were categorised and mapped using ArcMap version 10.6.1 (ESRI 2018). The model's ability to correctly discriminate the observed prevalence was analysed using the receiver operating characteristic (ROC) analysis in the statistical software STATA/IC 15.1.

3. Results

3.1. Dataset for analysis

Our final dataset for analysis included a total of 878 (54.3%) male and 738 (45.7%) female patients out of which a total were 349 (21.6%) paediatric patients and 1267 (78.4%) adult patients. A total of 168 (10.4%) patients re-presented to the ED, with 86 (51.2%) of these being unplanned re-presentations due to complications, and 82 (48.8%) being planned ED reviews. Of the patients who re-presented to the ED 31 (18.5%) were paediatric patients and 137 (81.5%) were adult patients. A total of 260 (16.1%) patients were admitted to a ward for surgery or other treatments. The most frequently reported bite location was the upper body with 868 (53.7%) cases, followed by lower body with 341 (21.1%) patients, head or face or neck with 247 (15.3%), and multiple with 65 (4.0%). There was no bite location recorded in 95 (5.9%) cases. Large dogs were responsible for 79 (4.9%) cases, followed by medium dogs with 76 (4.7%) cases, small dogs with 61 (3.8%) cases, and mixed dogs with 7 (0.4%). There was no information recorded on dog size in 1393 (86.2%) cases. The dog was known to the victim in 202 (12.5%) cases, unknown to the victim in 111 (6.9%) cases, and was not recorded in 1303 (80.6%) cases. Prior to being bitten 135 (8.4%) patients reported they were trying to separate fighting dogs, 39 (2.4%) were interacting in some way with a dog other than separating a fight and playing, 33 (2.0%) were playing with the dog, and 1409 (87.2%) did not have their prior behaviour recorded. A total of 77 (4.8%) patients were outside at the time of the bite incident, whilst 46 (2.8%) were bitten in a family member's, friend's, neighbour's, residence or workplace, 27 (1.7%) were bitten in their own residence, and 1466 (90.7%) reported no information on the location of the incident. The number of dog bite records do not increase over time in this study but there are fluctuations between peaks and troughs (Fig. 2).

3.2. Risk factors associated with paediatric patients

The results of the univariable analysis for the probability of paediatric dog bite hospitalisations indicated that paediatric cases tend to be significantly higher in males ($P = 0.051$), attending the Logan hospital ($P < 0.001$), bitten in their own residence (vs. outdoors; $P = 0.002$), more likely to sustain bites to the head/face/neck (vs. upper body; $P < 0.001$) and be bitten while playing with dogs (vs. separating fighting dogs; $P < 0.001$) (Table 2). However, after multivariable adjustment we found that paediatric patients were 14.65 times more likely ($P < 0.001$) to be bitten on the head or face or neck compared to the upper body and 4.95 times more likely ($P = 0.035$) of being bitten on the lower body compared to the upper body. Our multivariable results also showed that paediatric cases were significantly more likely to be bitten by larger dogs compared to adult patients (OR 0.25 95%CI: 0.07–0.88; $P = 0.030$).

3.3. Risk factors associated with dog bite injuries to the head/face/neck

Univariable analysis for risk factors associated with bite injuries to the head/ showed that these cases tend to be significantly more likely in the 0–16 age group ($P < 0.001$), to attend the Queensland Elizabeth Hospital (vs. Logan hospital; $P < 0.001$), to be bitten by dogs in their own residence (vs. outdoors; $P = 0.005$), to be bitten by a dog that is known to the victim ($P = 0.008$), to be bitten by a small breed dog (vs. large breed dog; $P < 0.001$) and be doing an activity not associated with separating fighting dogs (vs. separating fighting dogs; $P < 0.001$) (Table 3). After multivariable adjustment the probability of dog bite head injuries our results indicate that children (ie. 0–16 age group) are more likely to sustain such injuries than any other age group ($P < 0.001$) and that small dog breeds are 6 times more likely to inflict head injuries compared to largedogs ($P < 0.001$).

Table 2

Results of univariable analysis for risk factors associated with paediatric patients.

Variable	Univariable analysis		Multivariable analysis	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Sex				
Male	Reference		Reference	
Female	0.75 (0.56–1.00)	0.051	0.81 (0.25–2.58)	0.716
Facility				
LGN	Reference			
QEII	0.14 (0.29–0.58)	<0.001		
RED	0.89 (0.67–1.19)	0.444		
PAH	0.05 (0.02–0.15)	<0.001		
Location of incident				
Outdoors	Reference			
Workplace or other residence	0.80 (0.34–1.89)	0.616		
Own residence	3.54 (1.57–7.99)	0.002		
Bite location				
Upper body	Reference		Reference	
Lower body	1.79 (1.24–2.60)	0.002	4.95 (1.12–21.99)	0.035
Head or face or neck	9.64 (6.48–14.32)	<0.001	14.65 (4.67–45.94)	<0.001
Multiple	1.08 (0.70–1.66)	0.741	0.78 (0.06–10.58)	0.852
Dog type				
Known to victim	Reference		Reference	
Unknown to victim	0.51 (0.31–0.84)	0.009	0.29 (0.05–1.63)	0.156
Dog size				
Large	Reference		Reference	
Medium	0.83 (0.37–1.89)	0.662	0.20 (0.03–1.16)	0.073
Small	1.79 (0.94–3.37)	0.077	0.25 (0.07–0.88)	0.030
Prior behaviour				
Separate fighting dogs	Reference			
Other	7.11 (1.96–25.84)	0.003		
Playing with dog	20.08 (6.54–61.60)	<0.001		
Re-presentation				
No	Reference			
Yes	0.80 (0.55–1.17)	0.254		

3.4. Risk factors associated with re-presentation

At the univariable analysis none of the risk factors screened were significantly associated with the probability of re-presentation at the 0.05 significance level (Table 4). After multivariable adjustment our results indicate that the probability of re-presentation was marginally 4 times more likely in the 40–64 age group (vs. 0–16 age group; $P = 0.059$) and significantly more likely in patients bitten by larger dog breeds compared to medium sized breeds ($P = 0.027$).

3.5. Residual spatial dependence

Our residual semivariogram results suggested that paediatric cases, head injury cases and re-presentation cases clustered at a distance of 2.8 km, 1.5 km and 200 m of each other, respectively. The presence of a curve also meant that the final non-spatial multivariable models did not account for all of the spatial variation in the dataset (Fig. 3).

Table 3
Results of univariable and multivariable analyses for risk factors associated with dog bite head injury.

Variable	Univariable analysis		Multivariable analysis	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age				
0–16	Reference		Reference	
17–39	0.16 (0.11–0.23)	<0.001	0.25 (0.11–0.58)	0.001
40–64	0.11 (0.08–0.17)	<0.001	0.15 (0.05–0.44)	0.001
65-above	0.05 (0.02–0.14)	<0.001	0.14 (0.03–0.82)	0.029
Sex				
Male	Reference			
Female	1.07 (0.81–1.41)	0.627	0.90 (0.49–0.17)	0.747
Facility				
LGN	Reference			
QEII	0.48 (0.32–0.72)	<0.001		
RED	0.88 (0.60–1.29)	0.507		
PAH	0.63 (0.37–1.07)	0.087		
Location of incident				
Outdoors	Reference			
Workplace/other residence	5.07 (1.48–17.35)	0.010		
Own residence	5.21 (1.63–16.68)	0.005		
Dog type				
Known to victim	Reference			
Unknown to victim	0.35 (0.16–0.76)	0.008		
Dog size				
Large	Reference		Reference	
Medium	1.04 (0.39–2.82)	0.932	1.13 (0.41–3.03)	0.802
Small	5.76 (3.07–10.78)	<0.001	6.12 (2.92–12.76)	<0.001
Prior behaviour				
Separate fighting dogs	Reference			
Other	18.71 (4.96–70.66)	<0.001		
Playing with dog	16.38 (4.56–58.78)	<0.001		
Re-presentation				
No	Reference			
Yes	0.84 (0.60–1.18)	0.314		

Table 4
Results of univariable and multivariable analysis for risk factors associated with re-presentation.

Variable	Univariable analysis		Multivariable analysis	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Age				
0–16	Reference		Reference	
17–39	1.03 (0.66–1.62)	0.887	3.20 (0.63–16.23)	0.161
40–64	1.43 (90.97–2.11)	0.070	4.86 (0.94–25.10)	0.059
65-above	1.57 (0.88–2.80)	0.125	4.22 (0.42–42.20)	0.220
Sex				
Male	Reference		Reference	
Female	1.21 (0.90–1.63)	0.201	0.79 (0.36–1.73)	0.556
Facility				
LGN	Reference			
QEII	1.03 (0.66–1.62)	0.887		
RED	1.43 (0.97–2.11)	0.070		
PAH	1.57 (0.88–2.80)	0.125		
Location of incident				
Outdoors	Reference			
Workplace/other residence	0.39 (0.10–1.49)	0.169		
Own residence	0.69 (0.15–3.22)	0.637		
Bite location				
Upper body	Reference		Reference	
Lower body	0.90 (0.61–1.33)	0.607	1.70 (0.60–4.76)	0.316
Head or face or neck	0.77 (0.55–1.09)	0.142	1.36 (0.39–4.74)	0.629
Multiple	0.97 (0.60–1.56)	0.908	0.65 (0.12–3.52)	0.613
Dog type				
Known to victim	Reference			
Unknown to victim	0.58 (0.28–1.18)	0.133		
Dog size				
Large	Reference		Reference	
Medium	0.36 (0.12–1.05)	0.062	0.29 (0.10–0.87)	0.027
Small	0.36 (0.10–1.24)	0.104	0.34 (0.08–1.37)	0.128
Prior behaviour				
Separate fighting dogs	Reference			
Other	0.59 (0.17–2.12)	0.426		
Playing with dog	0.48 (0.09–2.46)	0.376		

3.6. Predictive risk mapping

Our findings indicate that the probability of paediatric dog bites is significantly higher in male compared to female patients (Coef. = −0.26 95%CrI −0,51–0.01) and in locations with lower socioeconomic status compared to more affluent areas (−0.23 95%CrI −0.443 −0.03). Our predictive mapping results also suggest that the probability of paediatric dog bite patients to be highest along most suburbs of Logan and Redland city council areas, ranging from 25% to >40% of dog bite hospitalisations in some suburbs within those city councils (Fig. 4). Areas with a higher predicted probability of head injuries included the outer northern, southern and western suburbs of Brisbane, significantly associated with patients aged 0-16yo (Coef. = 2.0 95%CrI 1.70 2.34) and marginally associated with areas within an increased distance to hospital (Coef. =0.32 95%CrI −0.01 0.63), lower socioeconomic status (Coef. = −0.14 95%CrI −0.29 0.01) and higher population densities (Coef. = 0.12 95%CrI −0.04 0.30). In addition, our results for the predicted probability of dog bite re-presentation indicate it to be highest in a discrete set of suburbs of inner Brisbane (between 10 and 15%) and the west and south of Logan city council. While the north of the city is predicted to have the highest probability of re-presentations (25–30%) the associated uncertainty is high (SD = 0.20–0.30).

The ROC analysis revealed good discriminatory ability across all spatial predictive models. For the paediatric dog bite probability model
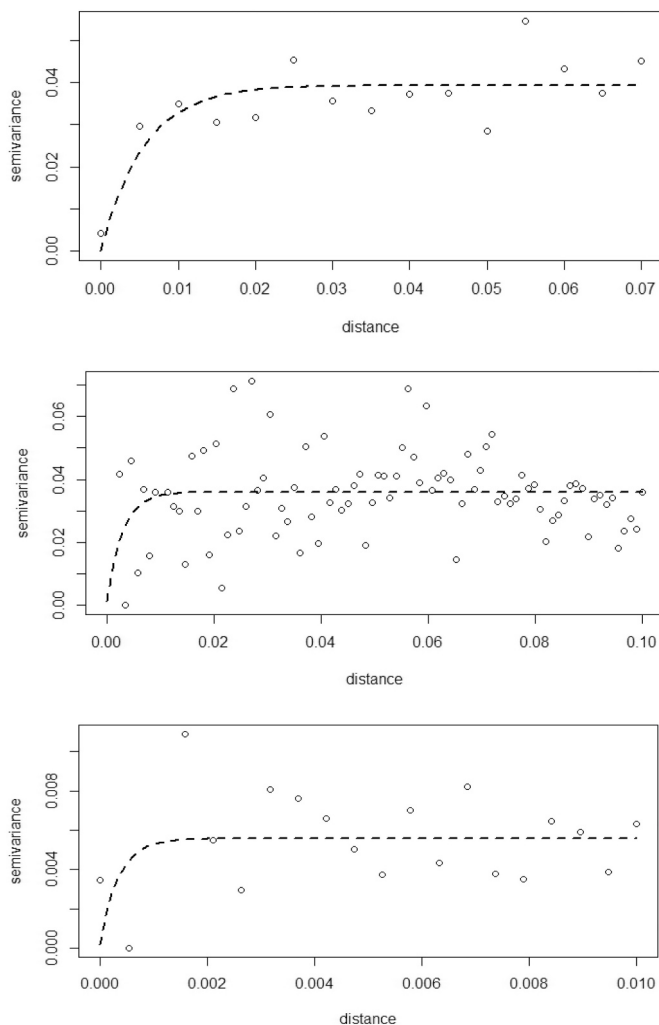
the AUC ROC was 0.87 (95%CI: 0.84 to 0.91) to discriminate areas under 20%. A ROC area of 0.99 with 95% confidence intervals 0.998 to 1.0 was identified for the model's ability to predict the prevalence of head injuries from dog bites under 10%, and a ROC area of 0.997 with 95% confidence intervals 0.99 to 1.0 for the model's ability to predict head injuries prevalence over 30%. A ROC area of 0.997 with 95% confidence intervals 0.992 to 1.0 for the model's ability to predict patients representing for dog bites under 10%. All of these indicated a very good discriminatory ability of the model.

4. Discussion

Our study provides much needed evidence regarding risk factors for dog bites for associated ED presentation types and utilised spatial analysis methods in order to better understand populations at risk in the Metro South region of Brisbane. To the best of our knowledge, this was

Fig. 3. Residual semivariograms *One decimal degree at the equator is approximately 111 km.

although at lower rates that head/face/neck. The higher likelihood of children to sustain head/face/neck injuries could be partly explained by the relationship and interactions of children with dogs, particularly if dogs are known to the child and whether the sort of activities at the time of the attack. Indeed our univariable results indicated that most paediatric injuries were more likely to be inflicted by known dogs, had happened in the child's household and were inflicted while playing with the dog; however after multivariable adjustment none of these factors retained significance. Dog bite injuries sustained to the head/face/neck which require rapid medical attention as literature reports that head injuries are more likely to results in severe injuries [14,36]. These injuries are challenging to manage in the ED, with issues such as threats to the patient's airway and special sense organs, often requiring involvement of multiple emergency clinicians and urgent consultation with other specialty teams (e.g. ophthalmology, plastic surgery, maxillofacial surgery) [39]. The results of our univariable analysis of probability of dog bites to the head/face/neck are concordant with those for paediatric cases in that it showed that the risk of a victim receiving a head injury decreases with age is more likely to occur in the own house and while carrying out an activity which does not involve separating fighting dogs.

One risk factor that often stands out in the literature as a determinant of the severity and likelihood of dog bites is dog breed and size. While previous evidence suggests that aggressive dog behaviours increase as a function of dog size [40], other studies have demonstrated that smaller dogs are more likely to bite in comparison to larger dogs [13,40]. Our analyses demonstrate that the effect of dog size on the risk of human ED presentations differs between the three clinical outcomes investigated. While our results suggest that larger dogs are over represented in paediatric dog bite risk, smaller dogs are significantly associated with dog bite head/face/neck injuries. This finding is at odds with a previous study reporting that large dogs are the most likely to cause bites to the head or face or neck of the victim [22]. Another important finding from our study is that the probability of re-presentation was significantly more likely in middle aged patients (ie. 40–64 age group) bitten by larger dog breeds. Taken together our findings confirm current debate around responsible ownership of large dogs as they remain the highest risk for paediatric and re-presentation cases. However, our findings also help reframe the discussion around the relationship between dog size and severity in that smaller dogs were found to be more likely to inflict bites to head/face/neck.

Our predictive maps revealed significant geographical variation in the predicted probability for each dog bite outcomes investigated in this study. An important finding is that clusters of paediatric cases tend to be larger in size (~3 km) compared to clusters of dog bite injuries to the head/face/neck and re-presentations which, based on our results, are more circumscribed (1.5 km and 200 m respectively). The fact that all our three clinical outcomes (ie. paediatric cases, dog bite injuries to the head/face/neck and re-presentations) were still spatially clustered after accounting for individual and contextual factors indicate that behaviour and more proximal factors associated with dog ownership may play an important role in the spatial distribution of these outcomes. Further studies advancing investigations into the role of behavioural factors could be targeted to the areas identified to be at higher risk, including Logan and Redland city councils in the case of paediatric cases and dog bite head/face/neck injuries and a smaller set of inner Brisbane suburbs in case of re-presentations. Furthermore, our results also demonstrate the importance of targeting health education and promotion towards populations in high risk areas with lower socioeconomic status, particularly to reduce the probability of paediatric cases and dog bites to the head/face/neck.

The results of this study should be interpreted in light of some important limitations. First, utilising healthcare admission and discharge data significantly underestimates the true burden of dog bites in the community [25]. International data suggests that hospital records alone provide insufficient information to determine the real burden associated with dog bites [41]. The majority of bites do not require

the first Australian study which analysed patient hospitalization clinical record data using spatial analysis to investigate the epidemiology of dog bite injuries in paediatric vs. adult patients, dog bite head injuries and the probability of patient re-presentation to the ED. The outcomes of interest in our investigation have important clinical relevance. Compared to adults, paediatric dog bite injuries require more individualised care and tend to have a greater resource burden at their initial presentation. Dog bite head injuries are more likely to require involvement of other specialty teams (e.g. plastics and reconstructive surgery) and are more complex to manage due to their close association with important anatomical structures. The Australasian College for Emergency Medicine defines patient re-presentation to the ED as one of the key quality standards for emergency departments, and high re-presentation rates imply suboptimal emergency clinical care [35].

Our results indicate that dog bites in the Metro South region of Brisbane impart considerable public health burden in the paediatric population and result in ward admission to close to one quarter of bite patients presenting to ED. These results are concerning given the growing trend of dog ownership in Queensland. Our findings suggest that paediatric dog bite cases admitted to ED are close to 15-fold more likely to suffer bites to the head/face/neck which is consistent with previous literature indicating that paediatric patients are more likely to suffer bites to the this region of the body compared to adults [10–13,15,22,36–38]. Our results also indicate that paediatric patients are also more likely to sustain dog bite injuries to the lower body
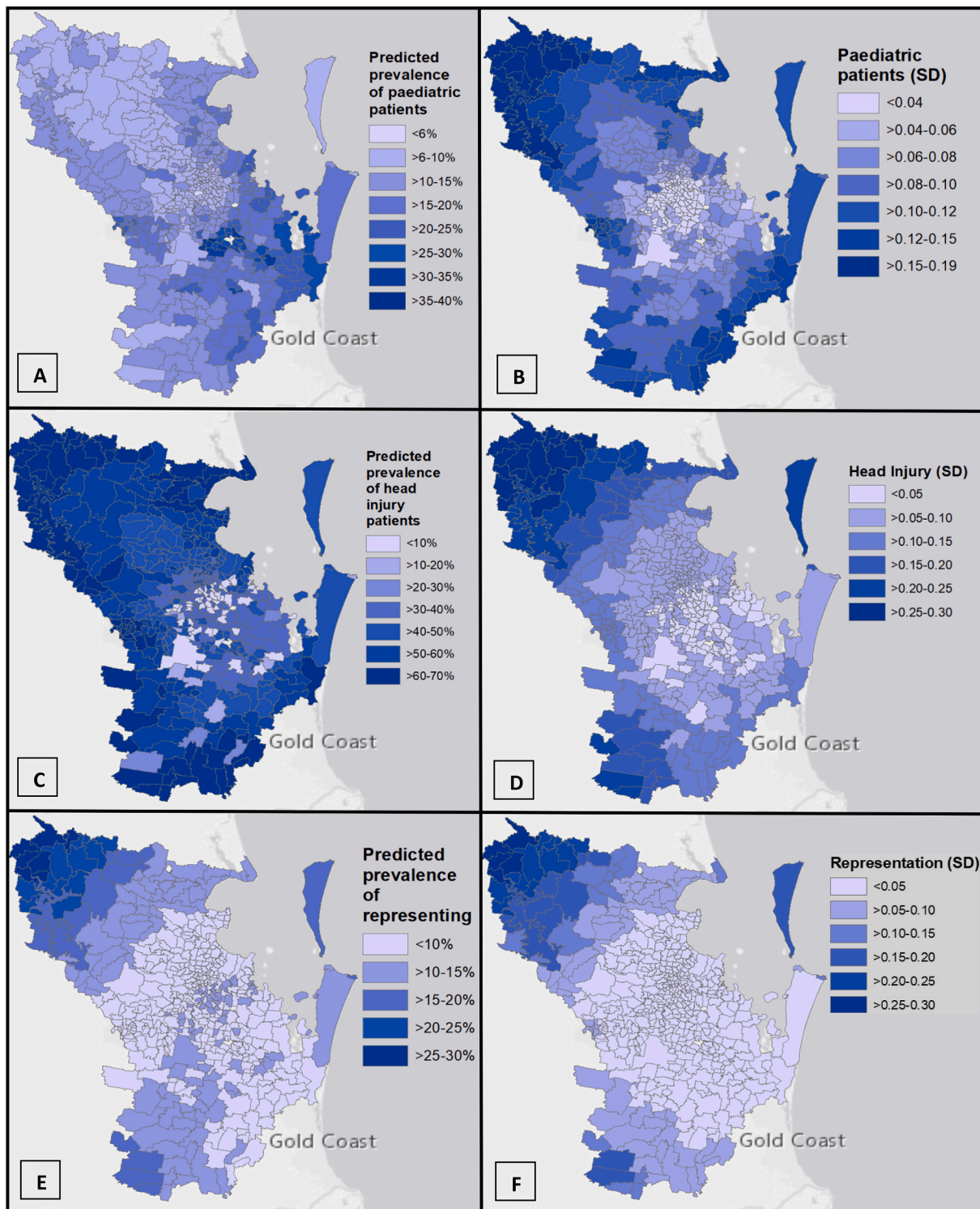
Fig. 4. Predicted probability of paediatric dog bite patients, head injuries from dog bites, and re-presentation for dog bites in Brisbane with the associated standard deviation maps The predicted prevalence is shown for paediatric dog bite patients (A), head injuries from dog bites (C), and re-presentation for dog bites (E). The associated standard deviation maps (B,D,E) indicates the uncertainty surrounding the predicted probability of each of the clinical presentations.

treatment at hospitals thus hospital data sources cannot be considered representative of the true incidence in the wider population [41]. Second, our data reveal significant gaps in the way ED clinicians record epidemiological data on dog bites with a significant proportion of the data missing information (in some instances >80% missing data) on the characteristics of the offending dog and the context of the bite incident. In this study dog size was determined by the UK Kennel Club

classifications, based on the breeds described in the electronic record which might not be accurate. This denotes a critical gap in the way which hampers a comprehensive evaluation of evidence-base to inform protective policy towards dog attacks in the community. Despite this level of data attrition our findings carry important public health implications. First, many regions identified by our study require community-level public health interventions in order to prevent the likelihood of

severe dog bite injuries [3]. Second, our research suggests that severe dog bites are an important source of paediatric injuries, particularly within the <18 year age group [3]. Third, small scale research such as this study highlights the potential of nationwide case-based surveillance of animal bites as an effective means of improving national-level estimates of their true burden [8,21].

In conclusion, our study demonstrates that dog bite injuries are geographically clustered to a small set of suburbs in the Metro South region of Brisbane and associated with important demographic and socioeconomic indicators of the underlying populations. The findings of this study can assist local councils at-risk of increased dog-bite ED presentations to design targeted community based intervention to the paediatric population of affected areas with the aim of reducing the burden and trauma associated with these events.

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Declaration of Competing Interest

There were no conflicts of interest to report.

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